GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION

Date: 2/6/79

Project Title: Metallurgical Analysis of Failed Metal Gears

Project No: A-2320

Project Director: Dr. B. R. Livesay

Sponsor: Donald MacMillan & Son, Inc.

TERMINATED

Effective Termination Date: 1/31/79

Clearance of Accounting Charges: 1/31/79

Grant/Contract Closeout Actions Remaining:
NONE

- _ Final Invoice and Closing Documents
- _ Final Fiscal Report
- _ Final Report of Inventions
- _ Govt. Property Inventory & Related Certificate
- _ Classified Material Certificate
- _ Other _____

Assigned to: Applied Sciences Laboratory/SSSD (School/Laboratory)

COPIES TO:

Project Director
Division Chief (EES)
School/Laboratory Director
Dean/Director—EES
Accounting Office
Procurement Office
Security Coordinator (OCA)
Reports Coordinator (OCA)
Library, Technical Reports Section
Office of Computing Services
Director, Physical Plant
EES Information Office
Project File (OCA)
Project Code (GTRI)
Other _____

CA—4 (3/76)

A-2320

FR

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

December 13, 1978

Mr. Ken MacMillan
Donald MacMillan & Sons, Inc.
P.O. Box 557
Macon, Georgia 31202

Dear Mr. MacMillan:

This note is to inform you of our costs involved with the metallurgical analysis of your failed metal gears. The total charge was $920. Of this amount, $462 was analytical instrumentation charges (the scanning Electron Microscope, and Electron Microprobe) and the remainder covered specimen cutting and polishing, the analysis of microstructures, etc., and finally, the preparation of a report for you. Contained within this total also is the standard Georgia Tech indirect expense and fringe benefit charge which amounts to 85.83% of professional services charges.

Since I don't believe an account is currently in effect between The MacMillan Co. and Georgia Tech, the appropriate procedure would be to address a purchase order to the Georgia Tech Research Institute for these services. Your payment could accompany this purchase order if that is convenient.

I hope we have aided in the ultimate solution to your gear failing problem and we will be happy to help in any way we can in the future.

Sincerely yours,

B. R. Livesay, Ph.D.
Senior Research Scientist

BRL/gt

Project A-2320

METALLURGICAL ANALYSIS OF FRACTURED GEARS

Conducted for Donald MacMillan & Son Inc., Macon, GA

by

Dr. B. R. Livesay
Georgia Institute of Technology
Atlanta, Georgia 30332

The three copper alloy failed gears which you sent to us were sectioned and subjected to microstructural analysis. The sections were cut radially and parallel to the axis of the gears so that the sections appear as shown in Figure 1. Subsequent to standard metallurgical grinding and polishing procedures, the specimens were examined. Pitting was clearly evident throughout the material near the gear shaft. The pitting is visible even on the approximately one to one photographs contained in Figure 1. The letters in the notation, i.e., Figure 1A, denotes the gear arbitrarily labeled A. As seen in Figure 1A, the gross pitting extended throughout the shaft section of Gear A whereas the pits were smaller towards the central parts of the material in Gears B and C.

The sections were then etched and examined under higher magnification. Figures 2 show the microstructure at 100X for the material near the shaft for each of the three gears as indicated. Figure 3 was made of the material in the neighborhood of the gear teeth. You will note that small pits are still present in this region but of much smaller size and density than those present in the material near the shaft. In addition, details of the microstructure apart from the pits are quite different in the two regions. The dendrites are much larger in the

shaft region than in the tooth. Also, the phase seen as darker grey occupies a much greater volume of the material in the shaft region than in the tooth region. The composition of this phase was thus of interest so a compositional analysis was conducted on a piece of specimen B. These data are attached as Figures 4, 5, and 6.

The compositional analysis was carried out in the scanning electron microscope (SEM). SEM micrographs of this specimen are shown in Figures 7, 8, and 9. The magnification in Figure 7 is 200X but for Figures 8 and 9 2,000X. The composition of the regions is indicated for the points defined by the letters marked on Figures 8 and 9. The phase in question is obviously rich in tin (Sn) and thus likely to be somewhat brittle.

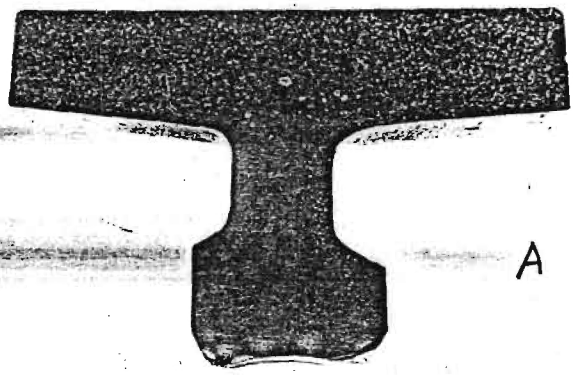
Conclusions

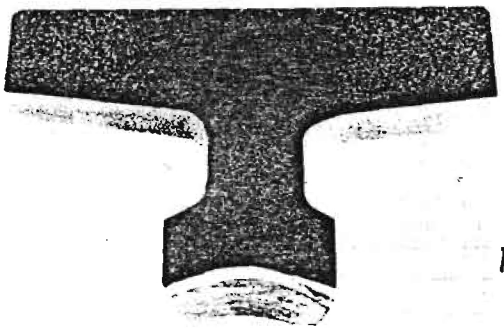
The material in the regions near the shaft has a high pitting density. Cavities of this sort sharply reduce the fatigue strength of any structural member. Pits are also found distributed throughout the remainder of the material but both the density and cavity size is somewhat lower. It was also clear that the microstructure of the near-shaft material is different from that of the near-tooth alloy. The large dendrites and correspondingly larger Sn rich phase might reduce fatigue strength also. However, the pits are so dominant that it is felt here that the fatigue fractures are due to fatigue crack initiation at the pit cavities.

There is probably a relationship between the grain structure and the pitting observed in the material regions. A detailed knowledge of the specific alloy mixture, casting parameters and mold geometry would be necessary here before intelligent judgments would be possible concerning

the root cause for the faulty castings. For example, the rate at which heat is extracted from the melt and the location of risers can influence shrinkage and grain details. In addition, the melt itself is important for the possible inclusion of gases and impurities.

The question was posed at one time as to the possibility of Georgia Tech conducting fatigue tests on sections cut from the gears. Based on the geometry of the gears examined here, there appears to be sufficient material to design fatigue specimens which would permit an evaluation of fatigue strength even of material cut from different regions of a casting.





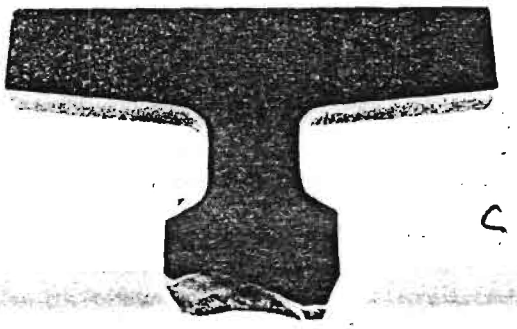
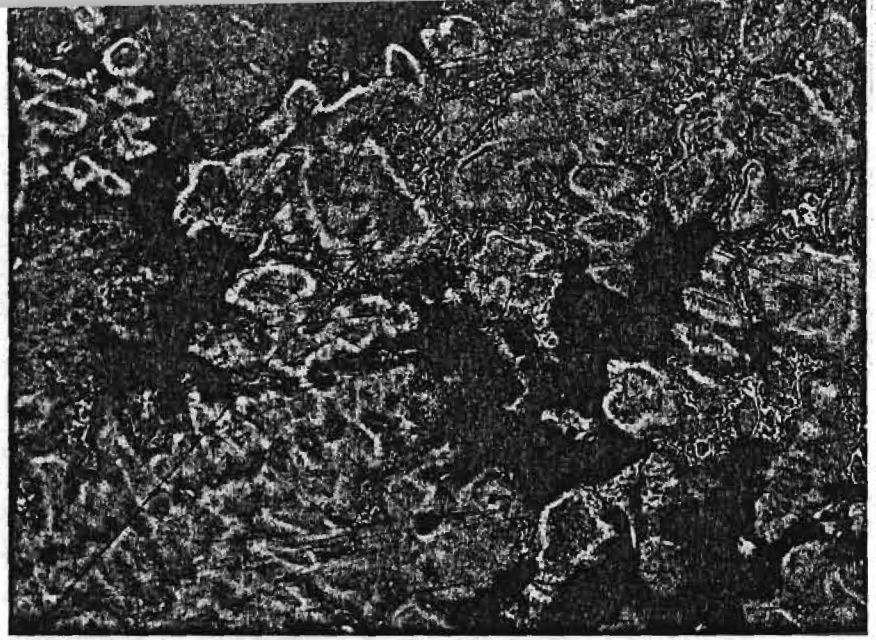
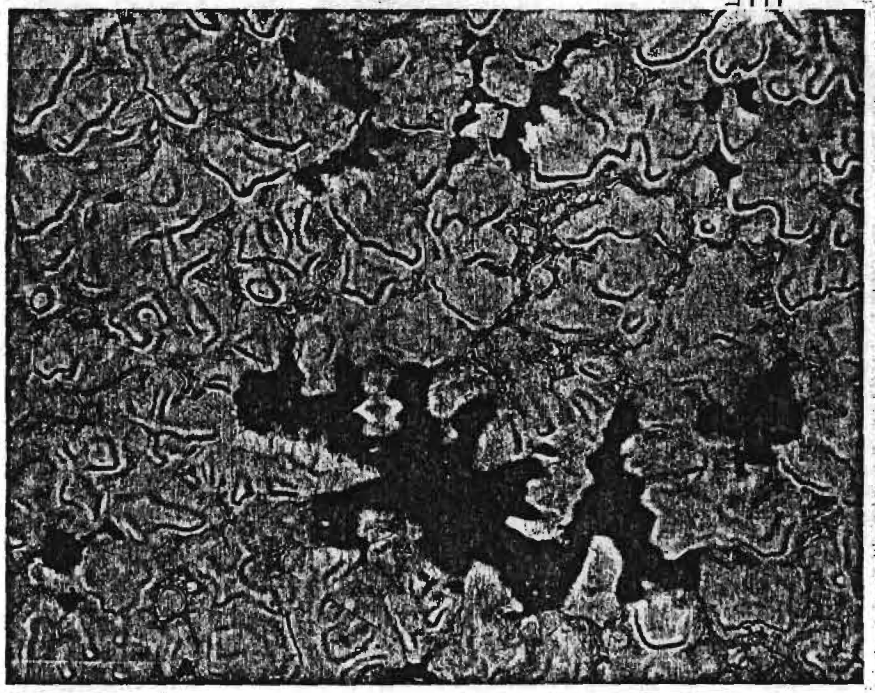


FIGURE 1 Photographs of Ground and Polished Sections Cut From Gears. The Upper Part of the Photos are From the Shaft Region and The Lower Part the Teeth. Magnification = About 1X



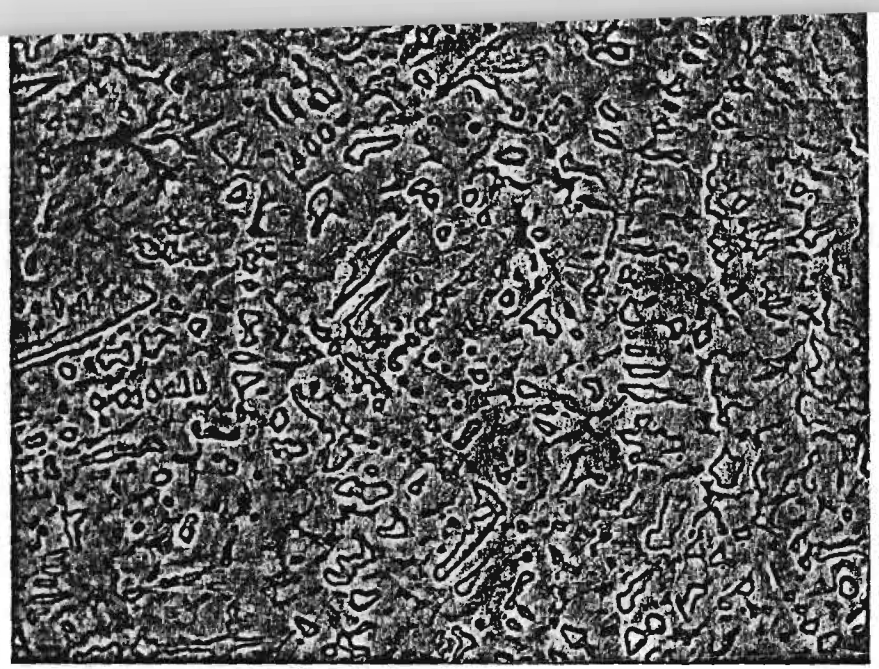
A-1 100x

B-.1 - 100x

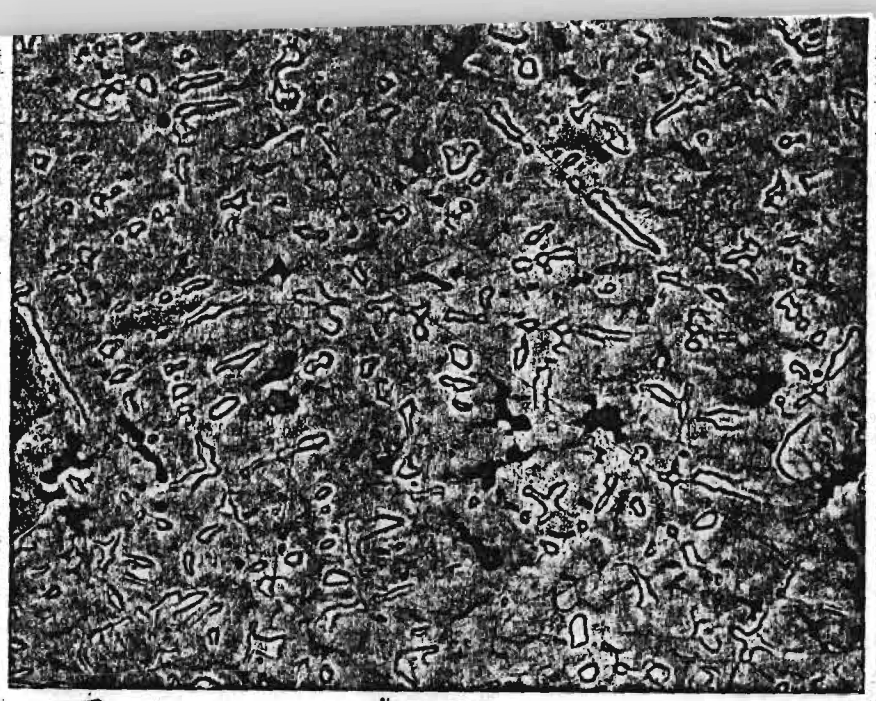


C-1 100x

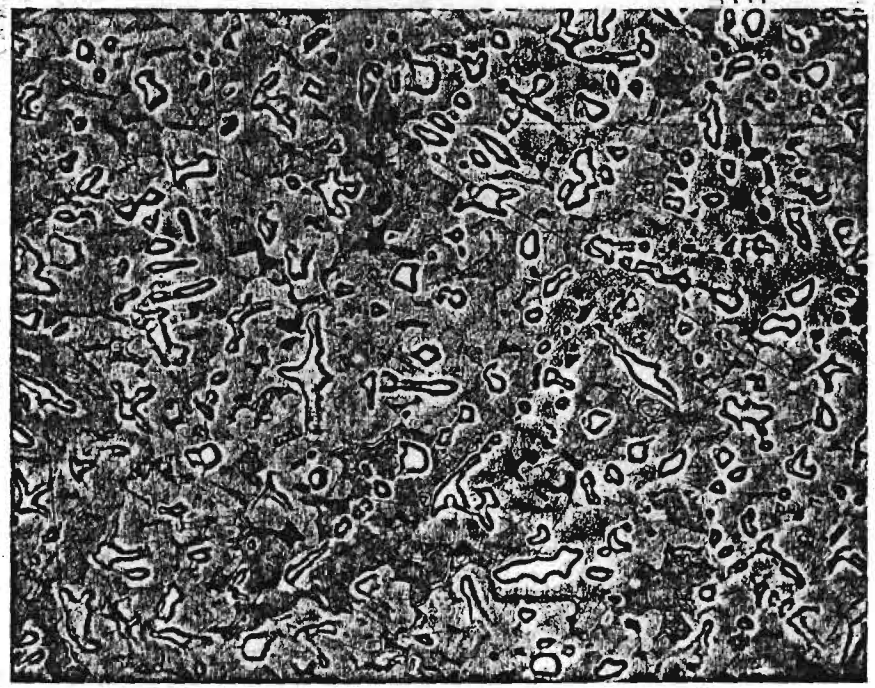
Figure 2 Micrographs of Gear Material Near Shaft, Magnification 100 X



A-2 100x



B-2 100x



C-2 100x

Figure 3 Micrographs of Gear Material Near Tooth of Gear

Magnification 100x

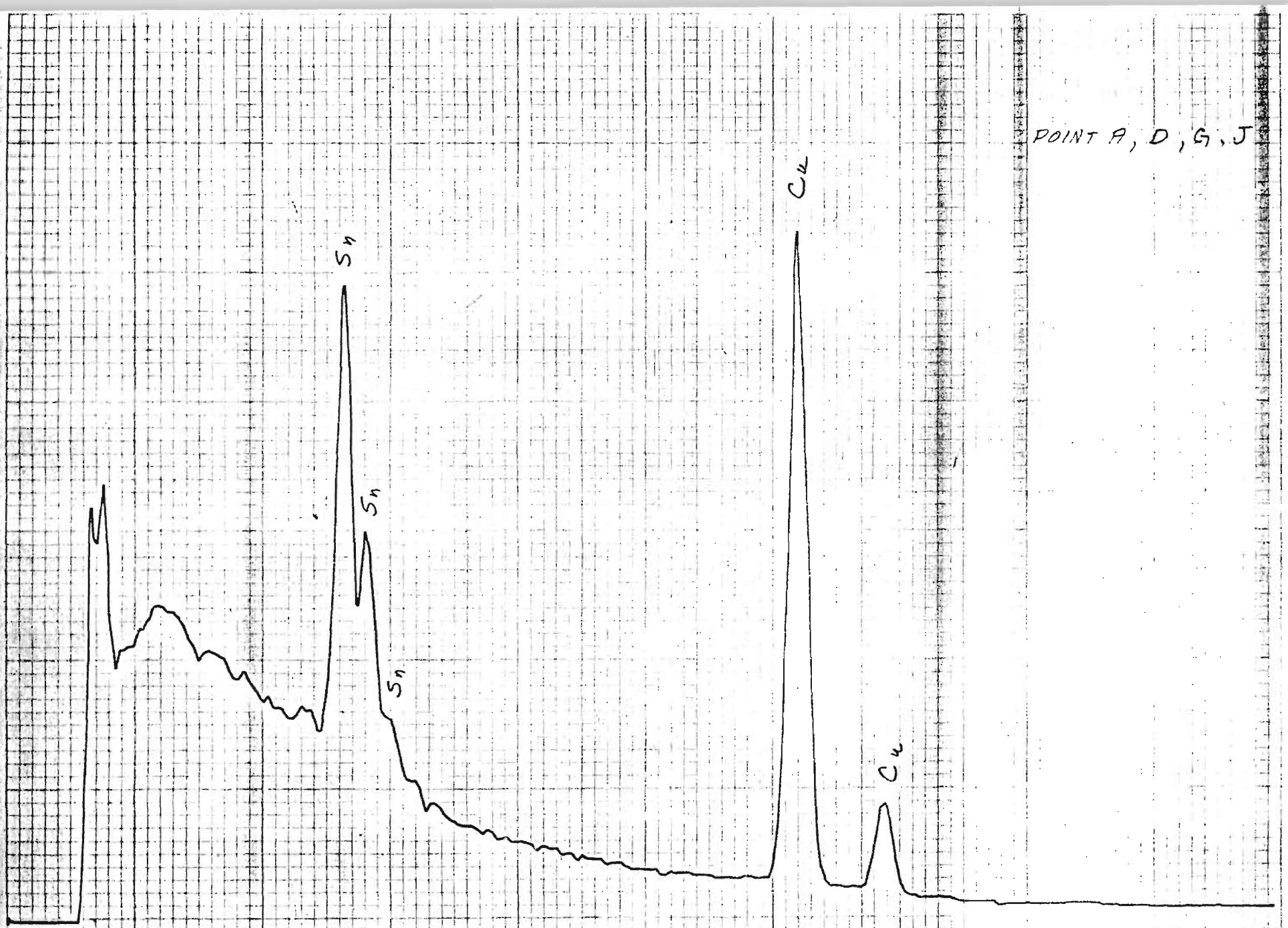


Figure 4 Composition of Material in Regions A, D, G and J as Defined in Figures 8 and 9. Note High Sn Content of Phase

Figure 5 Composition of Material in Regions B, C and I as Defined in Figures 8 and 9

Figure 6 Composition of Material in Regions F and H as Defined in Figure 9. Note P content of this Phase

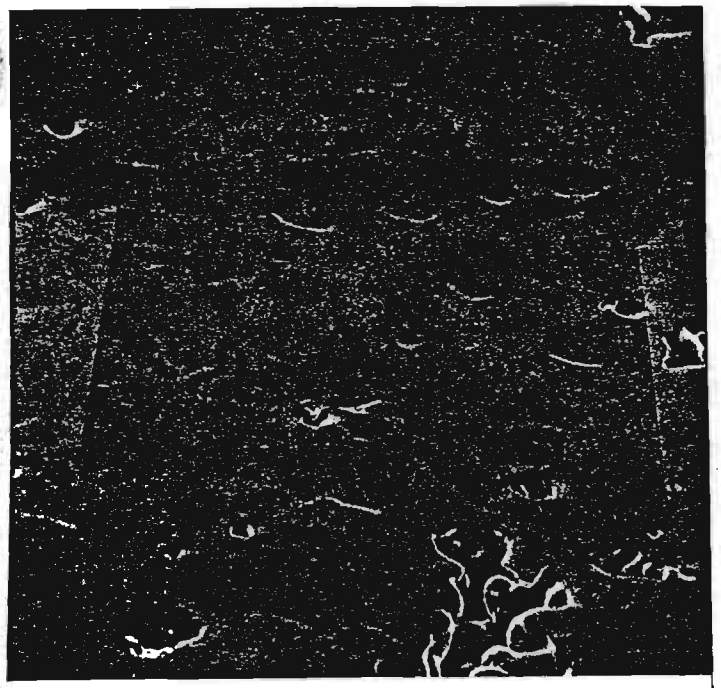


Figure 7
Scanning Electron Micrograph
of Material Near Shaft Taken
From Gear B.

Magnification 200 X

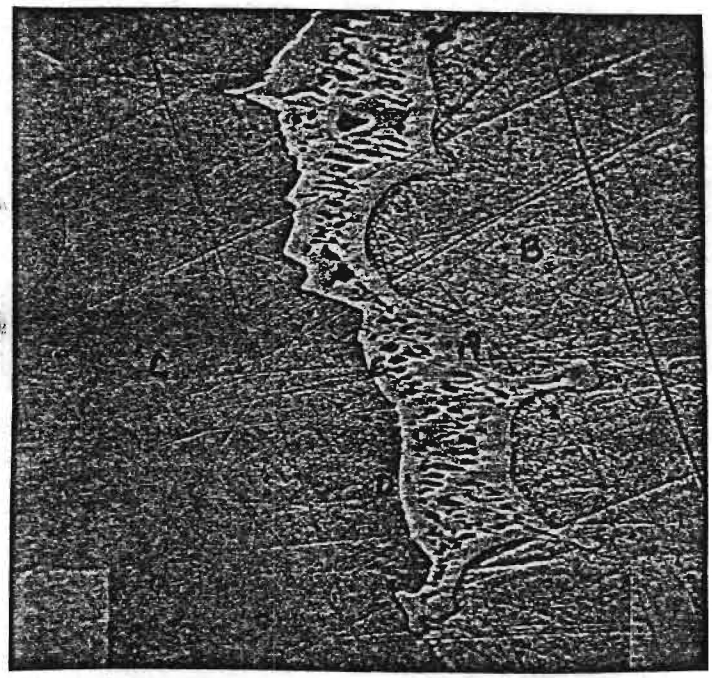


Figure 8

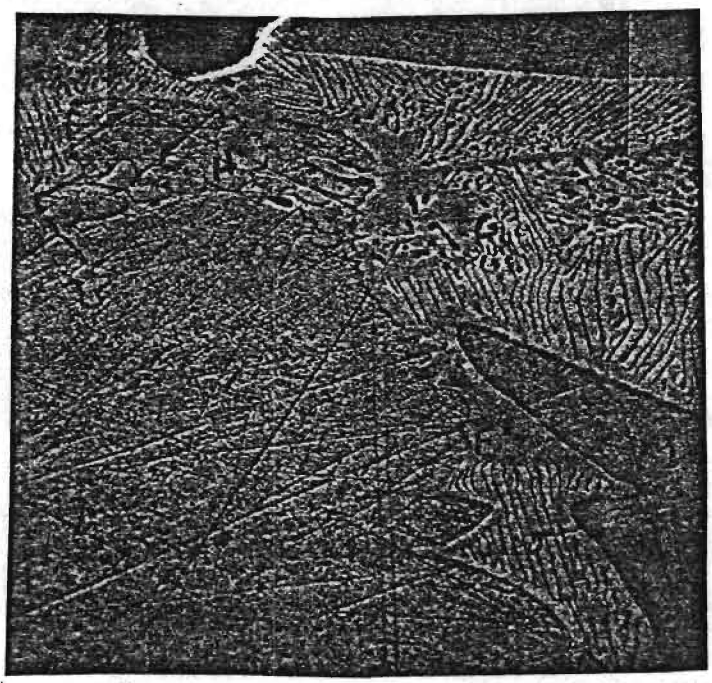


Figure 9

Scanning Electron Micrographs of Material Near Shaft Taken From Gear B
Magnification 2,000 X